PUBLICATIONS

OF THE

Astronomical Society of the Pacific.

VOL. XXV SAN FRANCISCO, CALIFORNIA, APRIL, 1913 No. 147

THE MAGNITUDE SCALE OF THE DURCHMUSTERUNG.

BY R. H. TUCKER.

At the August, 1912, meeting of the Astronomical and Astrophysical Society, Professor E. C. PICKERING presented a paper which included a comparison of the photometric magnitudes, published in volumes 70 and 74 of the *Harvard Annals*, with the magnitudes of the Bonn, Córdoba, and Cape volumes of the *Durchmusterung*. The brief abstract of this comparison, printed in *Science*, No. 940, of January 3, 1913, gives only the results at the fainter end of the D. M. scale, and some indications of variation in the scale of the southern portions.

There are four separate parts in the scheme of the *Durchmusterung*, thus referred to; and the northern and southern portions, observed at Bonn, should be treated individually. The northern sky was covered by ARGELANDER, and the limit of brightness to which the scheme was designed to be complete was set at ninth magnitude. The observations were made with a three-inch telescope, with dark field, and the faintest stars included were called 9½, though this limiting grade was certainly an elastic one, and many stars fainter than 9.5, on his scale, were observed.

The elastic nature of the lowest grade is of importance to observers, when selecting stars from the northern scheme. Stars recorded as 9.1 to 9.4, for instance, have been determined by several observations, in which some of the estimates were brighter than 9½, and the mean value for any star will probably be found to represent its brightness on the Argelander scale. But for 9.5 this relation no longer holds, and a star of

that grade may be very much fainter, down to the faintest observed. The faintest star visible should have been below eleventh magnitude, and it is nearly certain that some tenth-magnitude stars are included.

The next adjoining portion of the *Durchmusterung* extends to 23° south, and was observed by SCHÖNFELD, who had been associated with ARGELANDER in the observation of the northern sky. While his previous experience should have assured the extension of the same scale of magnitudes to the southern sky, the circumstances were somewhat changed. He observed with a six-inch telescope, the limit of visibility of which, with a dark field, should have been thirteenth magnitude. But, in order to insure greater precision in the places of the stars, he used a slightly illuminated field, and his visible limit of brightness was accordingly changed. His design, also, was to include all stars to the magnitude 9½, and he observed and recorded his grades down to tenth magnitude. His catalogue includes an average of eighteen stars to the square degree, while the catalogue of the northern sky includes fifteen to the square degree.

The Córdoba *Durchmusterung*, which began at —22°, thus overlapping one degree on SCHÖNFELD, was also planned to extend the Argelander scale of magnitudes to the southern sky. Our preliminary practice was done on portions of the northern zones, with careful comparison and discussion of results, usually made on the day following the observations of a night. There is probably no class of observing that demands more thorough special training. The aims of the *Durchmusterung* may be described as the complete inclusion of all stars to a definite limit of brightness, the ranking of all the stars observed on a graded scale of brightness, and the substantial precision of the places of the stars within the limits of error allowed for this class of work. These limits are, of course, greater than those of instrumental measures, but should be within those necessary for the certain identification of the stars. The importance of the several aims takes precedence in this order.

Atmospheric absorption plays a part in diminishing the apparent brightness of the stars, noticeable only at low altitudes. Its effect upon the stars observed by ARGELANDER would not

have much exceeded a tenth of a unit, down to the equator. The effect on the comparisons made at Córdoba, with the northern zones, would be still less. On the other hand, for the lowest altitudes at which SCHÖNFELD observed, the absorption would amount to 0.6 magnitude. Of course, the observer, for very low altitudes, can make allowance for the effect, if it may be sensible. The Córdoba observations were all made at small-hour angles, and, for the work hitherto published, the amount of absorption has probably been negligible.

The illumination of the field of view will cut down the limit of visibility and might affect the scale, but should not sensibly change the relative sequence in the grades of magnitude. No observations were made at Córdoba when any sky illumination from the Moon, though below the horizon, could be detected. The brighter background of the sky in the Milky Way can be conceived as affecting the scale, in the manner of artificial illumination, so that visual D. M. estimates might be too faint in that region.

The plan at Córdoba was to include all stars of the tenth magnitude, and, in order to be sure of accomplishing this end, many stars fainter than that grade were observed, consciously so very often. The published grade 10 is then an elastic grade, as was ARGELANDER'S 9.5, and while the scale up to 9.9, inclusive, represents the mean of several estimates in each case, and is a definite sequence of grades, the 10 may represent stars decidedly fainter than the position assigned to them in the scale. The observations were made with a five-inch telescope, for which the visible range would not extend much below twelfth magnitude. For the first twenty degrees, the observations were made with a dark field; and a test made by myself in the search for a twelfth-magnitude asteroid, upon the faintest stars seen, identified the missing object. No effort was ordinarily made to reach the faintest stars visible, and it is probable that no stars fainter than eleventh magnitude are included, though that limit may have been reached.

Internal evidence of the character of the scale may be found in the distribution of grades by the count of stars in the catalogue, and such evidence was published in my note in the *Astrophysical Journal* for May, 1898. In that note it was

shown that the Córdoba *Durchmusterung* includes a total equivalent to that of all the stars to the magnitude 10¼, on its own scale. The grade 10¼ would not be complete, on this basis, but enough stars fainter than that grade would be included to bring the total number up to the summation of all to 10¼ inclusive.

After my departure from Córdoba, when the third ten-degree section had been about one fifth completed, the observations were made with a faintly illuminated field. While this may have produced an effective increase in the precision of the places, it is certain to have cut down the limit of visibility, and it is not likely that anything as faint as eleventh magnitude would have been observed, in the continuation, mainly from 42° south. This change of observing practice is important, in view of the difference in scale found for the two portions by Professor PICKERING, which will be made the subject of further illustration later.

The Córdoba *Durchmusterung* has been published for the thirty degrees, 22 to 52, and the next following ten degrees was observed by Dr. THOME, and was practically all reduced before his death. The published part contains fifty-seven stars to the square degree.[1]

The fourth part of the *Durchmusterung*, done at the Cape of Good Hope, covers the southern sky from 19° south by photographic methods, thus including parts of the areas covered by SCHÖNFELD and at Córdoba. The places, derived from the measures of the plates, are much more precise than those of the visual *Durchmusterung*. The published magnitudes vary greatly in their limits for various parts of the sky, ranging from 9.6 to eleventh magnitude, and below. From my own discussion and comparison of its scale, as well as from estimates of others, the photographic list may be credited as pretty certainly including all stars to the magnitude 9.0 of the visual scale, excepting very red stars. Below that point it includes various numbers of stars in different portions; nowhere, however, certainly complete to a fainter grade than ninth.

The scale of magnitudes is based upon that of the Córdoba

[1] The proportion of Córdoba to ARGELANDER, 57 : 15 = 3.8, is closely that called for by the theoretical extension of the summation of the stars to one extra unit of the visual scale.

Zone Catalogue, the observations of which were all made by Dr. B. A. GOULD. The measurements of the photographic images were compared with this scale, and curves were derived to represent all parts. This would only carry the magnitudes down to about 9½; for stars estimated as fainter than that grade, in the *Zone Catalogue,* were pretty certainly observed under unfavorable conditions, and have been found, in the comparisons with D. M., to be at least as bright as the average 9½ of the same scale. In obtaining the constants of reduction for the D. M. places, I used every star from the *Zone Catalogue* that falls within the first twenty degrees. The zone estimates of magnitude were generally fainter than those of the D. M., the average difference amounting to one quarter at ninth magnitude. In the comparison of the photographic scale with the visual, in the note in the *Astrophysical Journal* referred to above, the estimates of the photographic D. M. were found to be in general about a quarter of a magnitude fainter than the visual outside the Milky Way; and nearly a quarter brighter in some portions of the Milky Way. This apparent change in scale corresponds with the statement of KAPTEYN that, as compared with the visual D. M., the fainter stars of the *Zone Catalogue* have been estimated half a magnitude brighter in the Milky Way than at the poles of that belt.

These points are necessary to be considered in the relation of the various scales, all of which are really extensions beyond the basis of comparison, which, for the visual scale, is the well-established and generally accepted magnitude scale of ARGELANDER. In volume 23, *Harvard Annals,* page 183, the photometric scale is stated to be a quarter of a magnitude brighter than the visual D. M. at ninth magnitude, with irregular variations in the difference for the brighter stars.

The photometric scale, while it is made up from measures of comparative brightness, has been finally reduced to the visual standard, as nearly as possible. For the fainter stars, the scale is, in general, an extension beyond the base of comparison, as in the visual estimates. The Harvard photometric work has been mainly done with three separate instruments and has been made up of many sections. The first photometer

had a telescope of $1\frac{1}{2}$ inches aperture, and *Polaris* was employed for a comparison star. This was succeeded by a four-inch telescope, and λ *Ursæ Minor* 6.6 was used for faint stars, as well as *Polaris*. For the southern sky σ *Octantis,* magnitude 5.5, was used as a comparison star; and throughout the photometric work many circumpolar stars were referred to as standards. In the latest photometer, largely used in the southern hemisphere, a 12-inch telescope was employed, and an artificial star of about the equivalent of sixth magnitude was used for comparisons. The results of this last photometer appear to have been reduced to the scale of the 4-inch, by comparisons of the measures common to both instruments. Large variations of wedge values have been included in the reduction of the photometric measures. Thus we find in a late publication, *Harvard Annals,* **72**, page 82, that the wedge constant varied 1.37 magnitude through a range of thirty-two divisions, following the first twenty-eight divisions. Beyond the part of the scale where sufficient comparisons can be made with visual estimates, the photometric measures must have a considerable amount of uncertainty.

Thus far the separate scales have been given in outline. The brief abstract in *Science,* referred to in the first paragraph above, has led me to supplement its figures by a more detailed comparison of the scales, taken from the same sources. Sufficient comparisons have been taken from the two series at Bonn and from —24° Córdoba to give the general trend of the respective differences, the published results in *Harvard Annals,* **70**, having furnished the figures in convenient form.

The results of the comparisons are tabulated below, as corrections to the visual scales, given by the photometric scale. The first column gives the magnitude from the visual D. M. The corrections to ARGELANDER, SCHÖNFELD, and Córdoba follow in order, tabulated for each tenth magnitude, and combined for approximate quarter magnitudes. The plus signs indicate that the visual estimates are brighter than the photometric. The lowest grade of ARGELANDER and that of Córdoba are bracketed, because they represent elastic estimates, as already explained. The lowest grade of SCHÖNFELD appears to correspond to the rest of his scale above.

In comparing the different visual scales with each other, from the indications of this table, it must first be assumed that the various sections of the photometric work, made with various instruments, are really homogeneous, and represent a uniform scale throughout the parts of the sky covered. The vast amount of careful and thorough investigation that has been bestowed upon the Harvard measures, represented fully in the text of many of the volumes, seems to be sufficient assurance that all possible has been done for this purpose. It is then possible to obtain the approximate relations of the several visual scales as outlined in the second part of the table below.

In the first part, ARGELANDER is in good accord with the photometric scale for the faint stars up to ninth magnitude. ARGELANDER is a quarter brighter at that point, and a decided rise is naturally indicated at the elastic grade 9.5 of the northern *Durchmusterung*.

SCHÖNFELD estimates brighter than the photometric scale throughout, the difference amounting to one and a quarter magnitudes at his lowest limit.

Córdoba estimates are brighter than the photometric by a full half magnitude, up to ninth, and the difference increases rapidly to one and a half at tenth magnitude, the published grade 10 being excluded, for reasons given above.

From these differences the relations of the visual scales are derived, in the second part of the table. Córdoba estimates are one-half magnitude brighter than ARGELANDER. They are one quarter brighter than SCHÖNFELD up to 9¼, beyond which point the two scales are in accord to 9.9. SCHÖNFELD is one quarter brighter than ARGELANDER to 9.4, and the elastic nature of ARGELANDER'S 9.5 is then evident. It would correspond nearly to SCHÖNFELD'S 9¾ and to the same at Córdoba.

CORRECTIONS TO D. M. SCALE OF MAGNITUDES.

From Photometric Measures, *Harvard Annals*, 70.

Mag.	Arg. N.D.M.		Sch. S.D.M.		Cor. D.M. —24°		Δ Visual D.M.		
							C — A	C — S	S — A
8.0	—0.1	—0.1	+0.1	+0.1	+0.5	+0.5	+0.6	+0.4	+0.2
8.1	0.0		+0.2		+0.4				
8.2	—0.2	—0.1	+0.1	+0.1	+0.2	+0.3	+0.4	+0.2	+0.2
8.3	—0.1		+0.1		+0.4				
8.4	—0.2		—0.1		+0.5				

Mag.	Arg. N.D.M.		Sch. S.D.M.		Cor. D.M. —24°		Δ Visual D.M. C — A	C — S	S — A
8.5	—0.1	—0.1	+0.1	+0.1	+0.5	+0.5	+0.6	+0.4	+0.2
8.6	0.0		+0.4		+0.5				
8.7	0.0		+0.2		+0.5				
8.8	+0.1	0.0	+0.3	+0.3	+0.5	+0.5	+0.5	+0.2	+0.3
8.9	0.0		+0.3		+0.6				
9.0	+0.1	+0.1	+0.4	+0.4	+0.6	+0.6	+0.5	+0.2	+0.3
9.1	+0.3		+0.6		+0.8				
9.2	+0.3	+0.4	+0.7	+0.7	+0.8	+0.8	+0.4	+0.1	+0.3
9.3	+0.5		+0.8		+0.8				
9.4	+0.6		+1.0		+0.9				
9.5	+1.4	[+1.4]	+1.1	+1.1	+1.1	+1.1	[—0.3]	0.0	[—0.3]
9.6			+1.1		+1.2				
9.7			+1.2		+1.1				
9.8			+1.4	+1.4	+1.6	+1.4		0.0	
9.9			+1.6		+1.4				
10			+1.3	+1.3	+1.8	[+1.8]		[+0.5]	
Average Δ.							+½	+¼	+¼

This table illustrates the relation between the photometric and visual scales, for the faint stars, but it gives no indication of which corresponds to the intrinsic brightness of the stars included. The photometric scale is evidently much the longer, for the range of brightness represented; that is, photometric estimates have a range of at least three units of magnitude, where the visual have two. Photometric measures of the faintest stars of SCHÖNFELD go to twelfth magnitude and beyond, and of the faintest of Córdoba to thirteenth and beyond. It is not likely that stars so faint could have been seen, during the observations of either visual scheme, and the lowest estimates of the photometric are unquestionably too faint. The photometric estimates of ARGELANDER'S 9.5 go down to twelfth magnitude and below, fainter stars than would have been visible in his telescope. His 9.5 are apparently nearly all estimated on the photometric scale as fainter than 10.

The figures of the table may be taken as a general confirmation of the brief statement of Professor PICKERING in the note referred to at the beginning of this. Combining the results of the two sections of Bonn, those of ARGELANDER and of SCHÖNFELD, the photometric estimates are about one unit of magnitude fainter than the visual at 9½, but SCHÖNFELD'S estimates are apparently one quarter brighter than ARGEL-

ANDER's at that point of the scale. The photometric estimates are one and a half units fainter than Córdoba, at the real 10 of the scale of the latter, which is in close agreement with SCHÖNFELD from nine to ten. As the Córdoba 10 includes many stars really estimated as fainter than true 10 on its own scale, the mean of the photometric estimates for that grade covers a wide range, over two units of the photometric scale. During part of the Córdoba work it was the custom to record stars fainter than 10 by the letter *a*, but the practice was not continued long. In combining individual estimates, this grade *a* was treated as 10 in the early work. But in the later volume, 42° to 52° south declination, this grade was apparently called eleventh magnitude, and there are a few stars printed as 10.5 in this later section. The change in the Córdoba scale below 42° may be explained by the change in observing practice, already noted in the preceding description. Further discussion of the two areas, which I expect to complete soon, will make this difference evident.

Some light upon the respective scales can be sought in the determination of the so-called absolute scale of magnitude, based upon counts of the stars; and this point I hope to take up later, with material already partially reduced.

The abstract of the note of Professor PICKERING gives the average deviation between the photometric and the photographic magnitudes, after applying corrections for the class of spectrum to the latter. These deviations were found to be ± 0.2 magnitude, after having been reduced one half by grouping stars on the same plate. In my comparison between the Córdoba magnitudes of the first ten degrees and those of the photographic *Durchmusterung*, the average deviation was found to be ± 0.3 magnitude, which apparently represents about the same degree of precision. In the present comparison, taking the average deviation from the photometric mean of the groups for each tenth of the scale, this is found to be ± 0.3 magnitude for the ARGELANDER from 8.0 to 9.4. For SCHÖNFELD it is ± 0.3 magnitude on the average, slightly larger for the faintest stars. For Córdoba it is ± 0.3 magnitude to 9.9 and ± 0.5 for the elastic grade 10. The respective scales appear to be each consistent, from the consideration of all these figures.

A final word of warning may be written for the benefit of those observers who desire precise places for comparison stars, for comets and asteroids. It is often assumed that the place of any D. M. star can be later measured with meridian circles. The telescopes of modern instruments are generally of smaller size than some of the older types. Instead of eight and nine inches, the latter theoretically capable of showing fourteenth magnitude in a perfectly dark field, the usual size is about six inches, theoretically capable of thirteenth magnitude under the same conditions. This is apparently an effective reduction of a whole magnitude.

With our instrument, of 6.4 inches aperture, I believe I can always count upon a satisfactory observation of a star of 9½, with sufficient illumination in the field. A star probably of tenth magnitude can be observed, with difficulty, under the best atmospheric conditions. With the 8-inch of the Dudley Observatory, used recently at San Luis, we often observed stars which I estimate as no brighter than tenth magnitude. In selecting stars from the northern D. M., they should be confined to the grade 9.4 and brighter, if possible. There will always be some uncertainty in securing observations of ARGELANDER'S 9.5.[1] From SCHÖNFELD'S D. M. the selection should be confined to stars of 9¼ or brighter, if a star of 9½ visual scale be taken as the usual limit of precise observation with modern meridian circles. In selecting from the Córdoba D. M., the corresponding limit should also be 9¼, the estimates for the faint stars being pretty certainly one-quarter magnitude too bright. I have recently found it not possible to observe a 9.8, and a 9.5 from SCHÖNFELD, though I observed one of 9.6. I have taken stars of 9.5 ARGELANDER, and recently one star not in his catalogue. These observations were made during a period when extremely red sky at sunset indicated a large amount of dust, probably volcanic, in the atmosphere, and a possible consequent diminution of transparency.

The meridian-circle observers at Córdoba usually found any of our D. M. stars estimated as fainter than 9.0 to be difficult.

[1] The limit set for the *Gesellschaft* zones was the D. M. 9.0, while the inclusion of previously observed fainter stars was also recommended.

That instrument, the original meridian circle mounted by Dr. GOULD, has an aperture of 4.9 inches only, and a twelfth magnitude star should be visible with its use in a dark field. The illumination in the field of a meridian circle cannot usually be as delicately adapted to the sight as in micrometer work with an equatorial. Tenth-magnitude stars can be observed, but the difficulties are sensible, and the uncertainty of the scale at the lower end of the visual *Durchmusterung* must be considered.

Astronomical photographs can go as far as desired, with sufficiently long exposures. But the unequal distribution of the faintest grades, published in the Cape *Durchmusterung,* raises the question of the actual brightness of the corresponding stars. Below ninth magnitude there are estimates extending over a considerable range, but so few proportionately of each grade that it would be hard to say what low grade is completely included. The colors of the faint stars are usually considered to show but little variety to account for this condition.

March 14, 1913.

THE INFLUENCE OF GRAVITATION ON LIGHT.

By HEBER D. CURTIS.

In *Annalen der Physik,* **35,** 898, 1911, Dr. A. EINSTEIN postulates the hypothesis that a ray of light will suffer deflection, or quasi-refraction, when passing through a powerful field of gravitation. This hypothesis is a result of the theory of relativity,[1] but from what we know of the behavior of light when passing through matter or a strong magnetic field, it is perhaps not inherently impossible that some such action should exist independently of the requirements of the theory of relativity. Physicists, it may be said parenthetically, are to-day divided into two warring camps on the subject of the theory of relativity, and whether it will ever become generally accepted is an open question, particularly as EINSTEIN has recently been forced to make certain rather radical alterations in the theory as originally stated by him. EINSTEIN puts forward

[1] *Publications, A. S. P.,* **23,** 219, 1911.